

IEEE Guide for Loading Dry-Type Distribution and Power Transformers

Sponsor

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Abstract: General recommendations for the loading of dry-type distribution and power transformers that have 80 °C, 115 °C, and 150 °C average winding rises and insulation systems limited to 150 °C, 180 °C, and 220 guide. Recommendations for ventilated, nonventilated, and sealed dry-type transformers having impregnated insulation systems are included.

Keywords: ambient temperature, cast-resin transformer, constant load, derating factors, hottest-spot temperature, loading capability, loading transformer, rated output, resin-encapsulated, solid-cast, time constant, transient loading

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Introduction

(This introduction is not part of IEEE Std C57.96-1999, IEEE Guide for Loading Dry-Type Distribution and Power Transformers.)

This guide covers loading dry-type distribution and power transformers with 80 °C, 115 °C, and 150 °C average winding rises, and has been developed to cover modern dry-type transformers through 10 000 kVA.

The 150 °C, 180 °C, and 220 °C insulation systems meet the thermal evaluation criteria established by IEEE Std C57.12.56-1986.^a

Work completed by the IEEE Insulation Subcommittee, comprising life test on transformer models, is the basis for the insulation life vs. temperature relationship, designated as minimum life expectancy in IEEE Std C57.12.56-1986, which in turn is based on the Arrhenius reaction rate theory. To avoid ambiguity, this guide will use the term *normal life expectancy* to indicate the life to be expected at a given temperature. The normal life expectancy at 140 °C, 175 °C, and 210 °C hottest-spot temperature in a 30 °C ambient for 80 °C, 115 °C, and 150 °C rise transformers, respectively, is 20 y.

The load profile used in the preparation of the loading tables in this guide was chosen as a representative daily cycle. Loss of life was determined by computer computation of the actual hottest-spot profile for the load cycle and ambient conditions. This method of calculation is more accurate than previous methods. Hand-calculation methods are illustrated in Clause 6.

The assumed characteristics were obtained by a consensus of users and manufacturers as being the best typical characteristics for modern transformers.

Annex A of this guide was developed for ventilated dry-type distribution and power transformers with solid-cast and/or resin-encapsulated epoxy windings manufactured in accordance with IEEE Std C57.12.01-1998. This annex contains complete information for loading cast-resin transformers. Reference to the main part of the guide is not required.

There are many cast-resin transformer designs available with different insulation temperature classes. Current practice by manufacturers has been to rely on tests of individual materials to determine the rated insulation temperature class to assign to their designs. Operating experience indicates that this gives acceptable life when cast-resin transformers are operated at nameplate ratings. At the present time industry has not established Arrhenius insulation aging curves to give loss of insulation life for cast-resin transformer windings operated above the rated insulation temperature class.

The loading recommendations and equations presented represent the best available information based on a consensus of users and manufacturers of cast-resin transformers at the time this guide was approved. Although this document is not a performance standard, it is expected that manufacturers will perform testing to substantiate their performance claims and demonstrate that the loading of their designs equals or exceeds these recommendations.

^aInformation on references can be found in Clause 2 and A.2.

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IEEE Guide for Loading Dry-Type Distribution and Power Transformers

1. Overview

1.1 Scope

This guide covers general recommendations for the loading of dry-type distribution and power transformers that have 80 °C, 115 °C, and 150 °C average winding rises and insulation systems limited to 150 °C, 180 °C, and 220 °C maximum hottest-spot operating temperatures, respectively. The guide includes recommendations for ventilated, nonventilated, and sealed dry-type transformers having impregnated insulation systems. For more specific recommendations for a particular transformer, the manufacturer of that transformer should be consulted.

1.2 General information

It must be recognized that the recommendations given in this guide are based solely on the thermal characteristics of dry-type transformers. Loads above rating, based on this guide, may be applied only after a thorough study has been made of all the other various limitations that may be involved. Among these limitations are gas expansion and pressure in sealed dry-type units and, in both ventilated and sealed transformers, the thermal capability of associated equipment, such as bushings, leads, connections, tap changers; and ancillary equipment, such as cables, reactors, circuit breakers, disconnecting switches, and current transformers. Also, limitations may be imposed by voltage regulation necessary for satisfactory operation of connected apparatus and by the increased operating costs due to the higher losses accompanying loads above nameplate rating. These may constitute the practical limit on load-carrying ability and should be considered before applying loads in excess of nameplate rating.

It is intended that dry-type transformers be installed based on the recommendations given in IEEE Std C57.94-1982.¹ If dry-type transformers are installed in subsurface vaults or enclosures of minimum size where the natural ventilation is insufficient to prevent marked changes in the ambient temperature with changes in transformer losses, then the increase in effective ambient temperature for expected increased transformer losses must be determined before loading limitations can be estimated.

Dry-type transformers are generally designed to permit loading in line with these guides, but if there are any questions as to the capability of a particular transformer to carry the desired load, the manufacturer should be asked for specific recommendations.

¹Information on references can be found in Clause 2.

1.3 Transformer life expectancy

Recommendations in this guide are based on life expectancy of transformer insulation as affected by operating temperature and time.

Transformer life expectancy at various operating temperatures is not accurately known, but the information given regarding loss of life of insulation is considered to be conservative, and the best that can be produced from present knowledge of the subject. (The effects of temperature on insulation life are being investigated continuously, and new findings may affect future revisions of the guide. The word *conservative* is used in the sense that the expected loss of insulation life for recommended load will not be greater than the amount stated.)

1.4 Transformer rated output

The rated kilovolt-ampere output of a transformer is that load that it can deliver continuously at rated secondary voltage and rated frequency without exceeding the specified temperature rise under usual service conditions, as described in Clause 4 of IEEE Std C57.12.01-1998. The term *rated output* or *rated load* used in this guide refers to nameplate rating of continuously rated transformers. For transformers that do not have a continuous rating, the manufacturer should be consulted for additional information when such information is not indicated on the nameplate.

The temperature rise on which the rating is based takes into consideration the experience of the industry regarding the following:

- a) Insulation life as affected by operating temperature; and
- b) The ambient temperature assumed to exist throughout the life of the transformer.

The actual output that a transformer can deliver at any time in service, without undue deterioration of the insulation, may be more or less than the rated output, depending upon the ambient temperature, altitude, and other attendant operating conditions.

1.5 Aging of insulation

Aging or deterioration of insulation is a function of time and temperature. Since, in most apparatus, the temperature is not uniform, the part that is operating at the highest temperature will ordinarily undergo the greatest deterioration. Therefore, aging studies consider the aging effects produced by the highest temperature.

Practically all of the data in reference to the aging of insulation at different temperatures has been obtained in laboratory tests in which the changes in mechanical or electrical properties, or both, have been measured. The relation between the life expectancy of insulation, as indicated by laboratory tests, and the actual life of a transformer is largely theoretical; thus loading based on such information should be tempered by sound judgment based on experience.

Because the cumulative effects of temperature and time in causing deterioration of transformer insulation are not thoroughly established, it is not possible to predict with a great degree of accuracy the length of life of a transformer, even under constant or closely controlled conditions, much less under widely varying service conditions.

The change in rate of deterioration with change in temperature has been widely studied, but the amount of change in actual transformer life with a change in operating temperature remains debatable. However, there is agreement that, in all of the methods of calculating the effect of operating temperature on insulation life,

higher than normal operating temperatures, whether they are due to loads above rating or to high ambients, result in some reduction in transformer life expectancy.

The many variables mentioned, and particularly the many varying conditions of load and ambient to which a transformer can be subjected in service, make it impossible to give precise rules for the loading of transformers. However, it is possible to give suggested loadings under specified conditions to assist the user in making loading decisions.

1.6 Ambient temperature

Ambient temperature is an important factor in determining the load capability of a transformer, since the temperature rise for any load must be added to the ambient to determine the operating temperature. Whenever the actual ambient temperature can be determined from readings taken at the time of the load being considered, such temperatures should be used to determine the winding hottest-spot temperature and the load capability of the transformer.

It is often necessary to predict the load that a transformer can carry with no sacrifice of life expectancy at some future time when the actual ambient temperature is unknown. For dry-type transformers used in indoor installations, the ambient temperature can be approximated from heating or air conditioning records of the installation. For transformers used outdoors, the ambient temperature for the month in which the expected load is anticipated can be obtained from reports gathered by the Climatic Services Branch of the National Climatic Data Center, which is a part of the National Oceanic and Atmospheric Administration. These reports are available for areas throughout the world.²

These ambients should be used as follows:

- a) For loads with normal life expectancy, use the average temperature over a period of years for the month involved.
- b) For short-time loads above rating with moderate sacrifice of life expectancy, use the average of the daily maximum temperatures for the month involved, averaged with similar values for the same month over a period of years.

1.7 Influence of ambient temperature

The average ambient temperature should cover periods of time not exceeding 24 h, with the maximum temperature not more than 10 °C greater than the average temperature. For each degree Celsius that the average temperature of the cooling air is above or below 30 °C, a transformer may be loaded below or above its nameplate kilovolt-ampere rating for any period of time, as specified in Table 1.

Loading on the basis of ambient temperature with the loads permitted by Table 1 can give approximately the same life expectancy as if the transformers had been operated at nameplate rating and standard ambient temperatures over the same period. The operation of transformers in cooling air above 50 °C, or below 0 °C, is not covered by Table 1; the manufacturer should be consulted for these operating conditions. Since the ambient temperature is an important factor in determining the load capability of a transformer, it should be controlled for indoor installations by adequate ventilation, and it should always be considered in outdoor installations.

1.8 Influence of altitude on loading

Because transformers are dependent upon air for dissipation of heat loss, the effect of the decreased air density due to high altitude is to increase the temperature rise of the transformers.

²This information can be obtained by writing to the National Climatic Data Center, Federal Bldg., Asheville, NC 28801.

Table 1—Self-cooled continuous loading on basis of average ambient temperature

Type of unit	Maximum rated hottest-spot temperature (°C)	Hottest-spot temperature in a 30 °C ambient (°C)	Percent of rated kVA/°C increase for average ambient less than 30 °C, or decrease for average ambient greater than 30 °C
Ventilated self-cooled	150	140	(0.57)
	180	170	(0.43)
	220	210	(0.35)
Sealed self-cooled	150	140	(0.65)
	180	170	(0.49)
	220	210	(0.40)

Transformers may be operated at rated kilovolt-amperes at altitudes greater than 1000 m (3300 ft) without exceeding temperature limits, provided the average temperature of the cooling air does not exceed the values of Table 2 for the respective altitudes. The data included in Table 2 apply to ventilated dry-type transformers only, and are not applicable to sealed and nonventilated dry-type transformers.

Table 2—Maximum allowable 24 h average temperature of cooling air, in °C, for operation at rated kVA under unusual temperature and altitude conditions

Type of Apparatus	Altitude			
	1 000 m (3 300 ft)	2 000 m (6 600 ft)	3 000 m (9 900 ft)	4 000 m (13 200 ft)
Class AA				
80 °C rise	30	26	22	18
115 °C rise	30	24	18	12
150 °C rise	30	22	15	7
Class AA/FA and AFA				
80 °C rise	30	22	14	6
115 °C rise	30	18	7	–5
150 °C rise	30	15	0	–15

Transformers may be operated in a 30 °C ambient at altitudes greater than 1000 m (3300 ft) without exceeding temperature limits, provided the load to be carried is reduced below rating by the percentages given in Table 3 for each 100 m (330 ft) that the altitude is above 1000 m (3300 ft).

Table 3—Rated kVA derating factors for altitudes greater than 1000 m (3300 ft) at 30 °C average ambient temperature

Type of transformer	Types of cooling	Derating factor (%) ^a
Dry-type, self-cooled	AA	0.3
Dry-type, forced-air-cooled	AA/FA and AFA	0.5

^aFor each 100 m (330 ft).

2. References

This guide shall be used in conjunction with the following publications. When the following standards are superseded by an approved revision, the revision shall apply.

IEEE Std C57.12.01-1998, IEEE Standard General Requirements for Dry-Type Distribution and Power Transformers Including Those With Solid-Cast and/or Resin-Encapsulated Windings.³

IEEE Std C57.12.56-1986 (Reaff 1998), IEEE Standard Test Procedure for Thermal Evaluation of Insulation Systems for Ventilated Dry-Type Power and Distribution Transformers.

IEEE Std C57.12.59-1989, IEEE Guide for Dry-Type Transformer Through-Fault Current Duration (withdrawn).⁴

IEEE Std C57.94-1982 (Reaff 1987), IEEE Recommended Practice for Installation, Application, Operation, and Maintenance of Dry-Type General Purpose Distribution and Power Transformers.

IEEE Std C57.110-1998, IEEE Recommended Practice for Establishing Transformer Capability When Supplying Nonsinusoidal Load Currents.

3. Basic loading conditions for normal life expectancy

3.1 Basic conditions

The basic loading conditions of a transformer for normal life expectancy are as follows:

- a) The transformer is continuously loaded at rated kilovolt-amperes and rated delivered voltage.
- b) The average temperature of the cooling air during any 24 h period is equal to 30 °C and the temperature of the cooling air at no time exceeds 40 °C.
- c) The altitude does not exceed 1000 m (3300 ft).

The hottest-spot temperature of the winding is the sum of the ambient temperature, the average temperature rise, and the hottest-spot allowance. For dry-type transformers operating continuously under the foregoing conditions, the hottest-spot temperature has been assumed to be 140 °C for transformers incorporating Class 150 °C limiting temperature insulation system; 170 °C for transformers incorporating Class 180 °C limiting temperature insulation system; and 210 °C for transformers incorporating Class 220 °C limiting temperature insulation system in a 30 °C ambient. These hottest-spot temperatures are expected to yield a normal life expectancy of 20 y for transformers covered in this guide.

Unusual service conditions, as given in 4.2 of IEEE C57.12.01-1998, are not covered by this guide.

Years of experience have indicated that a transformer rated in accordance with IEEE C57.12.01-1998 and operated under the foregoing conditions will have an economically acceptable life.

³ IEEE publications are available from the Institute of Electrical and Electronic Engineers, 445 Hoes Lane, P.O. Box 1331 Piscataway NJ 08855-1331 USA (<http://www.standards.ieee.org/>).

⁴ IEEE Std C57.12.59-1989 has been withdrawn; however copies can be obtained from Global Engineering, 15 Inverness Way East, Englewood, Colorado 80112, USA (<http://global.ihs.com/>).

3.2 Loading for life expectancy under specified conditions

Transformers may be loaded above rated kilovolt-amperes with no sacrifice of life expectancy if the loads and the load correction factors are applied under the conditions specified in 3.3, 3.4, 3.5, and 3.6.

The loading values and corrections given here are compromise values for a wide variety of transformers, and they have been selected so that allowable loads for practically all transformers covered by this guide will be at least as great as those given.

3.3 Loading determined by measured temperature

Dry-type transformers may be loaded above rating for any period of time with normal life expectancy, provided that the 24 h average hottest-spot temperature of 210 °C for sealed units; and 140 °C, or 170 °C, or 210 °C for ventilated units, is not exceeded for transformers with 150 °C, 180 °C, and 220 °C insulation systems, respectively. Hottest-spot temperatures may be obtained from hottest-spot temperature indicators if they are available.

Because of the variations in the gradient between the winding conductor hottest-spot temperature and the top air or top gas temperature of various designs under full load, neither inside air temperature for ventilated or nonventilated dry-type transformers nor top gas temperature should be used alone as a guide in loading transformers. However, either may be used as a guide in loading if the variation of the winding conductor hottest-spot rise over inside air or gas temperature is known.

3.4 Loading on the basis of short-time loads

The permissible load on dry-type transformers may be increased above rated load for short times by the multipliers shown in Table 4, Table 5, and Table 6, provided that

- a) The short-time peak load occurs not more than once in any 24 h period.
- b) The short-time peak load does not exceed the values listed in Table 4, Table 5, and Table 6.
- c) The short-time peak load follows, and is followed by, either a constant load or an equivalent constant load calculated by means of 6.1.
- d) The limitations of 1.2 and the basic conditions of 3.1 are met.

The values given in Table 4, Table 5, and Table 6 were obtained from a computer program described in 6.3 and a time constant of 30 min was used for each of the insulation systems. The time constant of 30 min was chosen as a conservative value for all dry-type transformers. If data is available for a different time constant, similar tables can be generated using the computer program in 6.3. Care should be taken by users of the computer program to avoid load cycles that exceed the maximum temperatures given in Table 4, Table 5, and Table 6 without a thorough investigation for abnormal consequences.

3.5 Effects of various factors existing at one time

When two or more of the following factors affecting loading for normal life expectancy exist at one time, the effects are cumulative and the increase in loads due to each may be added to secure the maximum suggested load. (Each increase must be based on rated kilovolt-amperes.)

- a) Loading on basis of ambient temperature;
- b) Loading on basis of measured temperature rise;
- c) Loading on basis of short-time loads above rating.

Table 4—Daily loads above rating to give normal life expectancy in 20 °C average ambient for transformers with a 30 min time constant

Peak load time in hours	Times rated kVA					
	150 °C insulation system following and followed by a constant load of					
	90%	Maximum hottest-spot temperature reached during load cycle (°C)	70%	Maximum hottest-spot temperature reached during load cycle (°C)	50%	Maximum hottest-spot temperature reached during load cycle (°C)
1/2	1.56	(210)	1.64	(217)	1.71	(220)
1	1.37	(196)	1.42	(203)	1.45	(206)
2	1.27	(181)	1.29	(185)	1.30	(186)
4	1.19	(165)	1.21	(169)	1.21	(169)
8	1.14	(155)	1.14	(156)	1.15	(158)
Peak load time in hours	180 °C insulation system following and followed by a constant load of					
	90%	Maximum hottest-spot temperature reached during load cycle (°C)	70%	Maximum hottest-spot temperature reached during load cycle (°C)	50%	Maximum hottest-spot temperature reached during load cycle (°C)
	90%	Maximum hottest-spot temperature reached during load cycle (°C)	70%	Maximum hottest-spot temperature reached during load cycle (°C)	50%	Maximum hottest-spot temperature reached during load cycle (°C)
1/2	1.49	(255)	1.57	(261)	1.64	(266)
1	1.32	(239)	1.36	(245)	1.39	(249)
2	1.23	(221)	1.24	(224)	1.26	(229)
4	1.16	(204)	1.17	(206)	1.18	(209)
8	1.11	(191)	1.12	(194)	1.12	(194)
Peak load time in hours	220 °C insulation system following and followed by a constant load of					
	90%	Maximum hottest-spot temperature reached during load cycle (°C)	70%	Maximum hottest-spot temperature reached during load cycle (°C)	50%	Maximum hottest-spot temperature reached during load cycle (°C)
	90%	Maximum hottest-spot temperature reached during load cycle (°C)	70%	Maximum hottest-spot temperature reached during load cycle (°C)	50%	Maximum hottest-spot temperature reached during load cycle (°C)
1/2	1.38	(282)	1.47	(290)	1.53	(292)
1	1.25	(269)	1.28	(274)	1.31	(278)
2	1.17	(251)	1.19	(254)	1.20	(259)
4	1.13	(238)	1.13	(239)	1.14	(241)
8	1.09	(227)	1.09	(227)	1.09	(227)

Table 5—Daily loads above rating to give normal life expectancy in 30 °C average ambient for transformers with a 30 min time constant

Peak load time in hours	Times rated kVA					
	150 °C insulation system following and followed by a constant load of					
	90%	Maximum hottest-spot temperature reached during load cycle (°C)	70%	Maximum hottest-spot temperature reached during load cycle (°C)	50%	Maximum hottest-spot temperature reached during load cycle (°C)
1/2	1.47	(204)	1.59	(216)	1.65	(220)
1	1.30	(192)	1.36	(201)	1.39	(206)
2	1.20	(177)	1.23	(183)	1.25	(186)
4	1.13	(164)	1.15	(168)	1.16	(169)
8	1.07	(153)	1.09	(156)	1.09	(156)
Peak load time in hours	180 °C insulation system following and followed by a constant load of					
	90%	Maximum hottest-spot temperature reached during load cycle (°C)	70%	Maximum hottest-spot temperature reached during load cycle (°C)	50%	Maximum hottest-spot temperature reached during load cycle (°C)
	90%	Maximum hottest-spot temperature reached during load cycle (°C)	70%	Maximum hottest-spot temperature reached during load cycle (°C)	50%	Maximum hottest-spot temperature reached during load cycle (°C)
1/2	1.42	(249)	1.53	(261)	1.59	(267)
1	1.27	(236)	1.32	(244)	1.35	(248)
2	1.17	(216)	1.20	(223)	1.22	(228)
4	1.11	(201)	1.13	(206)	1.14	(209)
8	1.06	(189)	1.08	(194)	1.08	(194)
Peak load time in hours	220 °C insulation system following and followed by a constant load of					
	90%	Maximum hottest-spot temperature reached during load cycle (°C)	70%	Maximum hottest-spot temperature reached during load cycle (°C)	50%	Maximum hottest-spot temperature reached during load cycle (°C)
	90%	Maximum hottest-spot temperature reached during load cycle (°C)	70%	Maximum hottest-spot temperature reached during load cycle (°C)	50%	Maximum hottest-spot temperature reached during load cycle (°C)
1/2	1.33	(278)	1.43	(289)	1.49	(291)
1	1.21	(267)	1.25	(274)	1.28	(278)
2	1.14	(251)	1.15	(254)	1.16	(257)
4	1.09	(237)	1.10	(240)	1.10	(240)
8	1.05	(225)	1.06	(228)	1.06	(228)

Table 6—Daily loads above rating to give normal life expectancy in 40 °C average ambient for transformers with a 30 min time constant

Peak load time in hours	Times rated kVA					
	150 °C insulation system following and followed by a constant load of					
	90%	Maximum hottest-spot temperature reached during load cycle (°C)	70%	Maximum hottest-spot temperature reached during load cycle (°C)	50%	Maximum hottest-spot temperature reached during load cycle (°C)
1/2	1.33	(192)	1.52	(214)	1.59	(217)
1	1.18	(179)	1.30	(199)	1.34	(204)
2	1.09	(166)	1.18	(183)	1.19	(184)
4	1.04	(157)	1.10	(168)	1.11	(170)
8	1.00	(150)	1.03	(155)	1.04	(157)
Peak load time in hours	180 °C insulation system following and followed by a constant load of					
	90%	Maximum hottest-spot temperature reached during load cycle (°C)	70%	Maximum hottest-spot temperature reached during load cycle (°C)	50%	Maximum hottest-spot temperature reached during load cycle (°C)
	90%	Maximum hottest-spot temperature reached during load cycle (°C)	70%	Maximum hottest-spot temperature reached during load cycle (°C)	50%	Maximum hottest-spot temperature reached during load cycle (°C)
1/2	1.33	(240)	1.48	(260)	1.55	(264)
1	1.19	(226)	1.28	(244)	1.31	(248)
2	1.11	(201)	1.16	(223)	1.18	(228)
4	1.05	(197)	1.09	(206)	1.10	(209)
8	1.01	(187)	1.03	(192)	1.04	(194)
Peak load time in hours	220 °C insulation system following and followed by a constant load of					
	90%	Maximum hottest-spot temperature reached during load cycle (°C)	70%	Maximum hottest-spot temperature reached during load cycle (°C)	50%	Maximum hottest-spot temperature reached during load cycle (°C)
	90%	Maximum hottest-spot temperature reached during load cycle (°C)	70%	Maximum hottest-spot temperature reached during load cycle (°C)	50%	Maximum hottest-spot temperature reached during load cycle (°C)
1/2	1.27	(273)	1.38	(285)	1.44	(290)
1	1.16	(262)	1.21	(262)	1.24	(276)
2	1.09	(246)	1.12	(255)	1.13	(257)
4	1.05	(235)	1.07	(241)	1.07	(241)
8	1.01	(222)	1.02	(226)	1.02	(226)